First RADAR Titan Flyby during S05/Ta

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November 5, 2004

- Sequence: s05
- Rev: 00A
- Observation Id: ta
- Target Body: Titan

1 Introduction

This memo describes the Cassini RADAR activities for the first Titan flyby on which SAR data will be acquired. The first Titan flyby occurs during the s05 sequence of the Saturn Tour. A sequence design memo provides the science context of the scheduled observations, an overview of the pointing design, and guidlines for preparing the RADAR IEB.

A number of engineering tests will be performed during this flyby. These engineering tests will check various aspects of instrument performance, spacecraft performance (ie., pointing), as well as providing valuable data on the assumptions and algorithms used to generate the IEB. The specific special tests are listed here:

1. PRF Hopping
2. Fixed Attenuator Stepping
3. BAQ mode switching (including 8-bit straight)
4. Scatterometer Compression Mode
5. B3 only SAR

These tests are described in more detail below in the relevant sections.

2 CIMS and Division Summary

Each RADAR observation is represented to the project by a set of requests in the Cassini Information Management System (CIMS). The CIMS database contains requests for pointing control, time, and data volume. The CIMS requests show a high-level view of the sequence design. Table 1 shows the CIMS request summary for this observation.

The CIMS requests form the basis of a pointing design built using the project pointing design tool (PDT). The details of the pointing design are shown by the PDT plots on the corresponding tour sequence web page. (See https://cassini.jpl.nasa.gov/radar.) The RADAR pointing sequence is ultimately combined with pointing sequences from other instruments to make a large merged c-kernel. C-kernels are files containing spacecraft attitude data.

A RADAR tool called RADAR Mapping and Sequencing Software (RMSS) reads the merged c-kernel along with other navigation data files, and uses these data to produce a set of instructions for the RADAR observation. The

CIMS ID	Start	End	Duration	Comments
00ATI_TAWARMUP001_RIDER	2004-300T10:15:09	2004-300T13:42:09	03:27:0.0	Warmup needed for Radiometry period following
00ATI_TAINSCAT001_PRIME	2004-300T14:11:09	2004-300T14:45:09	00:34:0.0	Inbound Scatterometry during Ta flyby
00ATI_TAPT4INMS001_PRIME	2004-300T15:18:09	2004-300T15:30:09	00:12:0.0	Ride along SAR of Titan with INMS.
00ATI_TAHIGHSAR001_PRIME	2004-300T15:30:09	2004-300T15:36:09	00:06:0.0	High resolution SAR imaging of Titan during closest approach period
00ATI_TALOWSAR001_PRIME	2004-300T15:36:09	2004-300T15:46:09	00:10:0.0	Low resolution SAR imaging during the post-closest approach time period
00ATI_TAOUTALT001_PRIME	2004-300T15:46:09	2004-300T16:00:09	00:14:0.0	Altimetry taken during the outbound trajectory of Ta
00ATI_TAOUTSCAT001_PRIME	2004-300T16:00:09	2004-300T16:45:09	00:45:0.0	Outbound Scatterometry during Ta flyby
00ATI_TAOUTRAD001_PRIME	2004-300T17:09:09	2004-300T20:30:09	03:21:0.0	Outbound Radiometry following the Ta flyby

Table 1: ta CIMS Request Sequence

RADAR instructions are called an Instrument Execution Block (IEB). The IEB is produced by running RMSS with a radar config file that controls the process of generating IEB instructions for different segments of time. These segments of time are called divisions with a particular behavior defined by a set of division keywords in the config file. Table 2 shows a summary of the divisions used in this observation. Table 3 shows a summary of some key geometry values for each division. Subsequent sections will show and discuss the keyword selections made for each division. Each division table shows a set of nominal parameters that are determined by the operating mode (eg., distant scatterometry, SAR low-res inbound). The actual division parameters from the config file are also shown, and any meaningful mismatches are flagged.

3 Warmup

The radar warmup rider begins at 2004-10-26T10:15:09.000 (-05:14:59.8) which is 15 minutes before the inbound ISS observation. This is done to accomodate the ORS instruments desire to not have the telemetry mode transition (to S&ER-5A) during their observation. The CIMS entries show the warmup ending before the next radar segment, but this is not actually the case. At the warmup CIMS end time of 2004-10-26T13:42:09.000 (-01:47:59.8) the spacecraft switches from wheels to thrusters. The instrument remains on through the transition, and eventually this minor CIMS error should be corrected.

During the warmup, the IEB will be set for slow speed radiometer only data as shown in table 4.

4 Div B: Inbound Scatterometer Scan - Probe Landing Site

The Ta radar observation is a fragmented pass with an inbound scatterometry scan that crosses the predicted probe landing point at -9.0 deg latitude and 192.0 deg W. longitude. The inbound scatterometry scan starts at 2004-10-26T14:11:09.000 (-01:18:59.8) with a duration of 34 min.

Division	Name	Start	Duration	Data Vol	Comments
a	Warmup	-6:40:0.0	05:20:0.0	4.8	
b	standard_scatterometer_inbound	-1:20:0.0	00:36:0.0	73.4	Inbound scatterometer scan of probe landing area
c	radiometer_fill	-0:44:0.0	00:39:30.0	0.6	Radiometer fill - no telemetry collected
d	standard_sar_hi	-0:04:30.0	00:09:45.0	139.8	SAR data collection starts as soon as beams on target
e	standard_sar_low_outbound	00:05:15.0	00:08:45.0	127.0	Outbound SAR low-res - ends early to avoid heating
f	sar_low_8_8	00:14:0.0	00:02:0.0	41.8	Outbound SAR low-res, 8 bits straight
g	sar_hi_B3	00:16:0.0	00:03:0.0	43.6	Test of B3 only SAR above 4000 km, during turn to Altimeter
h	standard_altimeter_outbound	00:19:0.0	00:11:0.0	56.1	
i	standard_scatterometer_outbound	00:30:0.0	00:00:36.0	1.4	Attenuator stepping test - manually overlaid replacing the RMSS generated scatterometer mode instructions
j	standard_scatterometer_outbound	00:30:36.0	00:45:24.0	92.6	Outbound scatterometer scan
k	scatterometer_compressed	01:16:0.0	00:06:0.0	14.0	Test of scatterometer compression mode at end of scan
l	standard_radiometer_outbound	01:22:0.0	04:08:0.0	14.9	Outbound radiometer scan - covers entire visible disk
Total				610.1	

Table 2: Division summary. Data volumes (Mbits) are estimated from maximum data rate and division duration.

Div	Alt (km)	Slant range (km)	B3 Size (target dia)	B3 Dop. Spread (Hz)
a	134544	off target	0.17	off target
b	25322	25904	0.03	315
c	13171	14591	0.02	604
d	1518	1949	0.01	2405
e	1627	1708	0.01	2343
f	3616	3666	0.01	1585
g	4182	4212	0.01	1451
h	5069	5070	0.01	1280
i	8545	8545	0.01	871
j	8740	8743	0.01	856
k	23966	23966	0.03	334
l	26001	26001	0.04	305

Table 3: Division geometry summary. Values are computed at the start of each division. B3 Doppler spread is for one-way 3-dB pattern.

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	-480.0	-400.0	yes	Delayed due to incomplete RADAR pass
end_time (min)	-300.0	-80.0	yes	Delayed due to incomplete RADAR pass
time_step (s)	2700.0	3600.0	yes	Used by radiometer only modes - saves commands
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	6 - Radiometer Only Mode
noise_bit_setting	don't care	4	no	
dutycycle	don't care	0.38	no	
prf (KHz)	don't care	1.00	no	
number_of_pulses	don't care	8	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	0.250	0.250	no	Kbps - actual data rate may be less
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 4: ta div_a Warmup block

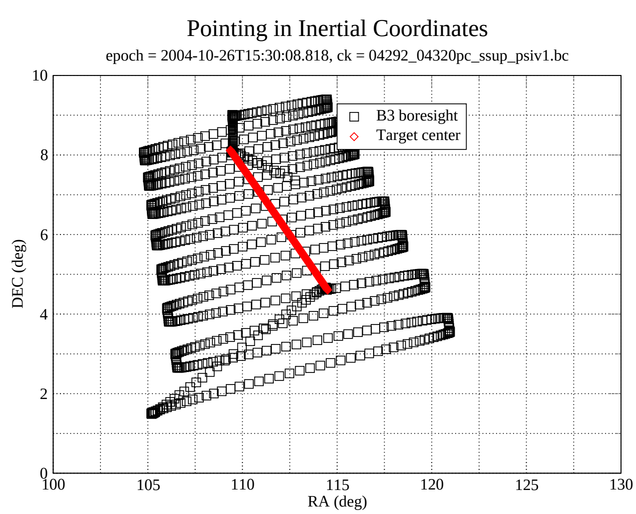

Figure 1: Inbound scan in inertial coordinates

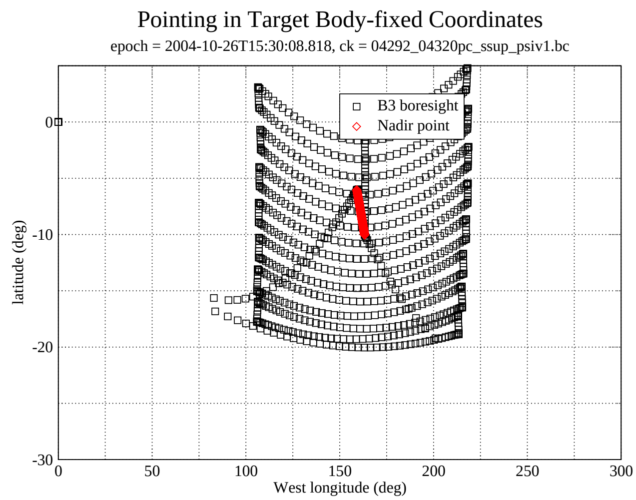

Figure 2: Inbound scan in target body-fixed coordinates

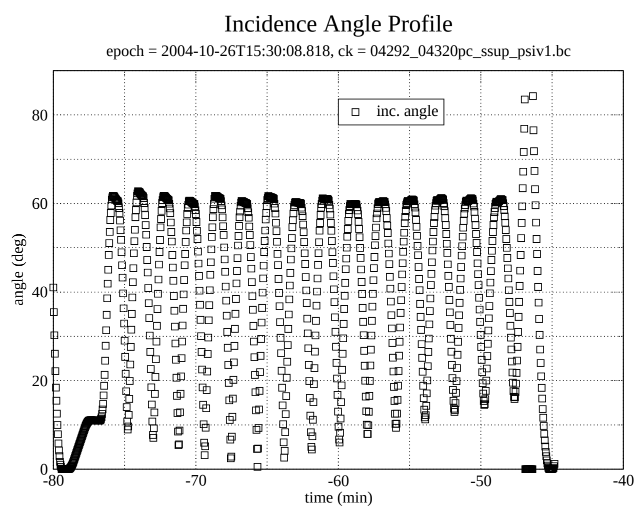

Figure 3: Incidence angle variation during inbound scatterometry scan

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	-80.0	no	
end_time (min)	varies	-44.0	no	
time_step (s)	don't care	5.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	8	8	no	8 - auto gain
noise_bit_setting	4	4	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.60	no	
prf (KHz)	1.20	1.20	no	
number_of_pulses	8	8	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	34.000	yes	Half pass allows a little more data volume for scatt
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 5: ta div_b standard_scatterometer_inbound block

Figures 1 and 2 show the pointing design for the scatterometry scan from the merged ckernel. In addition to hitting the predicted probe landing point, this scan sweeps nearly from limb to limb to provide incidence angle coverage and to catch a little bit of the bright region. Figure 3 shows the incidence angle coverage of this scan.

The IEB instructions for this inbound scatterometry block are generated by RMSS under the control of the set of config parameters shown in table 5. Although not shown in table 5, scatterometer mode operations use a transmit-receive window offset (TRO) of 6 which makes the echo window 6 PRI's longer than the number of pulses transmitted. This is done to increase the valid time for an instruction by letting the pulse echos walk through the longer echo window before the range-gate needs to be updated. This is particularly important during Titan scatterometry raster scans where the number of instructions needed to track the varying range can exceed the number available if a smaller TRO value is used. The positive TRO value also guarantees noise-only data in each burst which eliminates the need to insert special noise-only bursts.

5 Div C: Radiometer Fill - No Data Collected

After the inbound scatterometer scan, the spacecraft will switch to one of the optical remote sensing (ORS) instruments and enter a telemetry mode incompatible with RADAR. The RADAR is put into radiometer only mode, and the data generated is ignored by the spacecraft. The parameters for this fill period are given in Table 6.

6 Div D: INMS SAR Ride Along and Hi-Res SAR

Figure 4 shows the incidence angle profile during the hour centered on closest approach (c/a) which covers the SAR and altimeter intervals. Before c/a, INMS is prime and will be holding -X into the ram direction. During this time, it is important that the secondary axis be designated as -Z and targeted to the -Z axis in the RADAR IVD file. This

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	varies	-44.0	no	
end_time (min)	varies	-4.5	no	
time_step (s)	2700.0	2700.0	no	
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	
noise_bit_setting	don't care	4	no	
dutycycle	don't care	0.38	no	
prf (KHz)	don't care	1.00	no	
number_of_pulses	don't care	8	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	0.250	0.250	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 6: ta div_c radiometer_fill block

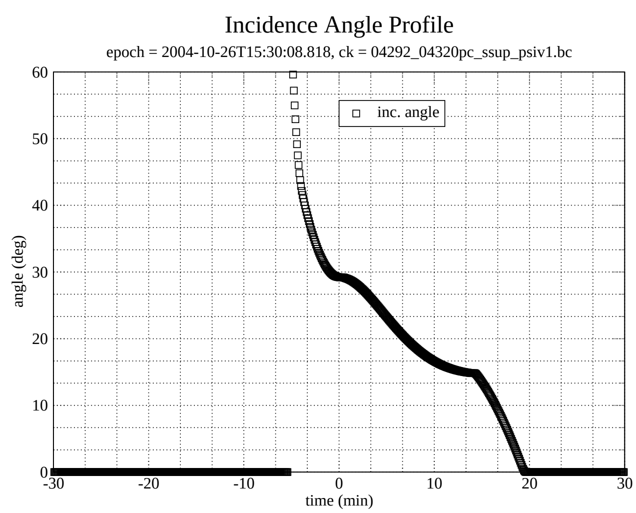

Figure 4: B3 boresight incidence angle during the time around c/a. This plot was generated using the SOP2 merged ckernel due to a problem with the SOPUD merged ckernel. It will be updated with the SSG merged ckernel when available. Note that the SOP2 merged ckernel has a one degree error in the Altimeter targeting.

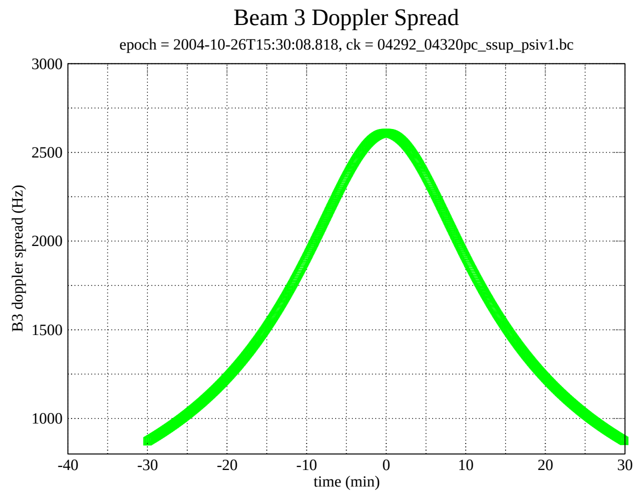

Figure 5: Nadir pointed B3 doppler spread during the time around c/a. Doppler spread is measured within the on-way 3 dB beam pattern.

strategy minimizes the transition time at c/a by rotating the s/c around its X-axis during the INMS observation to bring the RADAR beams close to their nominal SAR pointing.

During the INMS ride-along, the spacecraft attitude is not appropriate for SAR imaging until we get to within a couple of minutes of c/a. Outside of this time, the incidence angle is higher than the nominal SAR profile, and the beam orientations are not optimally lined up with the iso-doppler contours. Nonetheless, we plan to run the RADAR in Hi-Res SAR mode during the ride-along time to maximize the amount of image coverage we get. Future enhancements to the SAR processor may allows us to process more of this ride-along data into useful imaging coverage.

The PDT turn from INMS pointing to RADAR SAR pointing is commanded at c/a. There is a turn transition lasting about 1 minute. The transition occurs presumably because the attitude rates are not matched at closest approach (although the attitude itself is matched). It takes some time for the spacecraft to accelerate its attitude rates to match the SAR IVD profile.

The IEB instructions for the INMS ride-along time and the subsequent Hi-Res SAR interval are both generated by RMSS under the control of the Hi-Res SAR config parameters shown in table 7.

Prior to c/a, the range rate is high enough that the valid time calculation used by RMSS produces a negative value indicating that the built-in criteria for range gate tolerance can't be satisfied. When a negative valid time is generated, RMSS ignores the calculated value and instead uses the division time step to space instructions. The 2 second time step specified in table 7 results in a high instruction rate, however, this is acceptable for Ta because the RADAR does not operate for a full 10 hour flyby. A full 10 hour flyby would push the 500 fast field limit and require a more thrifty use of instructions.

Auto-Rad is set off for high-res SAR to allow the minimum burst period possible. This maximizes the number of looks during the critical c/a time when the number of looks is at a minimum due to the rapid movement of the beam patterns on the surface. The radiometer integration time is preset according to the approximate calibration obtained at Phoebe which is summarized in table 8.

The PRF profile and incidence angle profiles are optimized for maximum usuable imaging coverage. These profiles were produced for a 950 km flyby which is the most common SAR flyby altitude. The Ta flyby is at 1200 km c/a altitude, however, the same PRF and incidence angle profiles still give the same performance. When the c/a altitude becomes significantly higher (eg., 2000 km), then a new incidence angle profile should be used. The PRF profile is parameterized as a function of time with respect to c/a while the incidence angle profile is parametrized with respect to altitude above the sub-spacecraft point. These parameterizations are needed to allow the same profiles to be used for a group of flyby's with similar c/a altitudes. The PRF profile primarily covers the doppler spread of the beams (see figure 5) which varies with the changing angle between the spacecraft velocity vector and the look direction, but does not strongly depend on c/a altitude. The incidence angle profile on the other hand controls the balance between signal to noise ratio (SNR) and cross-track coverage which varies with altitude regardless of the time at which a particular

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	-6.0	-4.5	yes	Start when beams on target
end_time (min)	6.0	5.2	yes	1200 km flyby reaches 4000 km a little early
time_step (s)	don't care	4.0	no	Set by valid time calculation unless negative, then time_step is used instead
bem	11111	11111	no	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	2	2	no	
dutycycle	0.73	0.73	no	
prf (KHz)	don't care	0.00	no	RMSS follows profile
number_of_pulses	don't care	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	off	off	no	Set off for SAR modes to allow minimum burst time
rip (ms)	34.0	34.0	no	Calculated from radiometer calibration for prior observations
max_data_rate	255.000	239.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	on	no	
interleave_duration (min)	varies	8.5	no	

Table 7: ta div_d standard_sar_hi block

Parameter	Value
Radiometer gain (counts/s/K)	188
Receiver noise (K)	822
Titan antenna temperature (K)	88
integration time per window (ms)	34
Radiometer window offset (counts)	3550
Expected Titan counts per window	2267
On-scale Titan antenna temperature range	[-267,374]

Table 8: Radiometer Phoebe calibration (average of inbound and outbound) applied to Titan

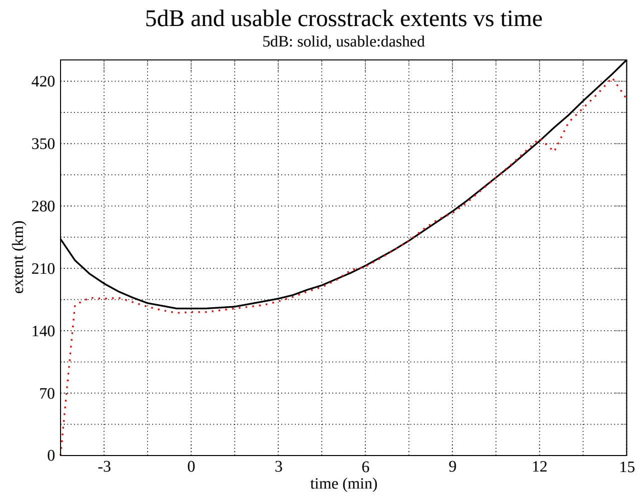

Figure 6: Usable cross track coverage predicted for the parameters in Div's D-F and the 950 km PRF and incidence angle profiles. Usable image area must have a signal to ambiguity ratio of at least 15 dB, a noise equivalent σ_0 of at least -10 dB, and a one way antenna gain of at least -5 dB relative to the beam maximum gain.

altitude occurs.

Figures 6 and 7 show the SAR image coverage performance expected from the pulse parameters in divisions D-F and the PRF and incidence angle profiles applied to this flyby geometry. Calculation of ambiguities assumes a Venus backscatter model for the Titan surface. Once actual data on the Titan backscatter response is obtained, this calculation can be updated. However, it is unlikely that changes in the model function will have much affect on the selection of parameters. Most of the constraints come from the evolution of the flyby geometry and the shape and position of the beam patterns.

The normal PRF profile is interrupted at two places in Hi-SAR and two places in Low-Sar to insert some PRF hops (plus and minus 10 percent). These steps in PRF will be used to resolve potential integer ambiguities in the doppler centroid where our knowledge of the doppler centroid is off by a multiple of the PRF. These special instructions may not be needed if reconstructed attitude and ephemeris data prove to be very accurate, however, they will be included until it is proven that they are not needed.

7 Div's E,F: SAR-Low

The low-res SAR interval starts at 00:05:15.0 when the altitude is 1627 km. At the end of the SAR-Low period, we will insert 2 minutes of 8-bit straight data collection near the maximum data pickup rate of 365 Kbps. This data will be used to check the 8-2 bit BAQ encoded data collected during the previous SAR intervals. The IEB parameters for the standard SAR-Low mode are set by division E, while the special 8-bit straight data are controlled by division F as shown in table 9

The data rate for this division is reduced a bit below the limiting value of 365 Kbps that was used on C43 to eliminate dropped packets. It appears that the Ta run is a little different from the C43 run because of updated ephemeris and attitude data which produce a slightly different sequence of PRI's.

The number of pulses is reduced below the number that could fill the round trip time because the DSS can't keep up. If the number of pulses is not reduced, then the burst period has to be lengthened to the point that fewer than 2 looks are obtained. We would like to always have at least 2 looks, so shortening the pulse train and the receiver window is a better alternative. Reducing the number of pulses will degrade SNR, and reduce azimuth resolution, however, azimuth resolution is much better than range resolution in SAR-Low mode, so this tradeoff should be acceptable.

Auto-rad is disabled during the low-SAR portions to prevent a gap from appearing in the SAR imaging swath. When Auto-rad is enabled, an instruction is needed which introduces a one-second gap in the SAR data.

Name	Nominal	e	f	Mismatch	Comments
mode	sarl	sarl	sarl	no	
start_time (min)	6.0	5.2	14.0	yes	Starts a little earlier due to 1200 km flyby vs 950 km
end_time (min)	19.0	14.0	16.0	yes	Ends early to avoid excessive heating
time_step (s)	don't care	3.0	4.0	no	Set by valid time calculation
bem	11111	11111	11111	no	
baq	0	0	5	yes	0 means 8 to 2, 5 means 8 bits straight
csr	8	8	8	no	8 - auto gain
noise_bit_setting	2	2	2	no	
dutycycle	0.73	0.73	0.73	no	
prf (KHz)	don't care	0.00	0.00	no	RMSS follows profile
number_of_pulses	don't care	0	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	1	no	
percent_of_BW	100.0	100.0	100.0	no	
auto_rad	on	off	off	yes	
rip (ms)	34.0	34.0	34.0	no	
max_data_rate	255.000	242.000	348.000	yes	8 to 2 reduces max data rate possible
interleave_flag	on	on	off	yes	
interleave_duration (min)	varies	8.0	10.0	no	

Table 9: ta div_ef standard_sar_low_outbound block

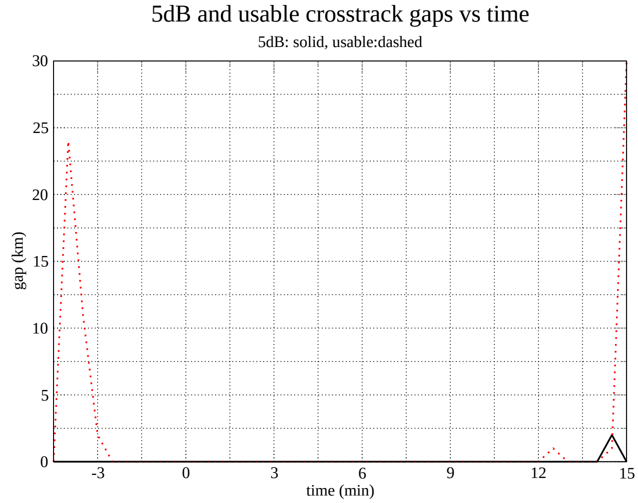

Figure 7: Extent of gaps in the cross-track coverage which do not meet the usable imaging criteria. These gaps occur when the PRF and incidence angle profiles are not optimized for the flyby geometry. The leading cause of gaps is the azimuth offset between beams 2 and 4 and beams 1, 3, and 5. The offset causes beams 2 and 4 to lead/lag the other beams on the surface. Thus they pass with a different incidence angle which can lead to gaps unless the incidence angle profile is adjusted to avoid this problem.

8 Div G: SAR-Hi B3 Only

During the slew from the SAR desired look angle profile (DLAP) to altimeter pointing, the instrment will switch back to high-res SAR mode and collect data from just beam 3. The higher gain of beam 3 should allow SAR imaging to continue above the 4000 km nominal limit. This division is included to collect data to try out this idea. If it works well (depending on how strong the surface backscatter is) then B3 only SAR imaging may be designed into future passes. The parameters for this division are shown in Table 10

9 SAR Resolution Performance

For all of the SAR divisions the effective resolution can be calculated from the following equations,

$$\delta R_g = \frac{c}{2B_r \sin\theta_i}, \tag{1}$$

$$\delta x = \frac{\lambda R}{2\tau_{rw} v \sin\theta_v}, \tag{2}$$

where δR_g is the projected range resolution on the surface, c is the speed of light, B_r is the transmitted chirp bandwidth, θ_i is the incidence angle, δx is the azimuth resolution on the surface, λ is the transmitted wavelength, R is the slant range, τ_{rw} is the length of the receive window, v is the magnitude of the spacecraft velocity relative to the target body, and θ_v is the angle between the velocity vector and the look direction. Figure 8 shows the results from these equations for the Ta flyby using the parameters from the IEB as flown. The calculations are performed for the boresight of beam 3 which is the center of the swath.

Projected range increases with decreasing incidence angle, so the range resolution varies across the swath with better resolution at the outer edge. The SAR pointing profile decreases the incidence angle as time progresses and altitude increases, so there is progressive deterioration of range resolution away from closest approach. The step change in range resolution occurs when the radar operating mode changes from Hi-SAR to Low-SAR which cuts the chirp bandwidth in half. The beam 3 only portion of the swath occurs during the turn to nadir, and the projected range resolution rapidly deteriorates as the incidence angle decreases toward zero.

Name	Nominal	Actual	Mismatch	Comments
mode	sarh	sarh	no	
start_time (min)	varies	16.0	no	
end_time (min)	varies	19.0	no	
time_step (s)	don't care	4.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	0	0	no	0 - 8 to 2
csr	8	8	no	8 - auto gain
noise_bit_setting	2	2	no	
dutycycle	0.73	0.73	no	
prf (KHz)	don't care	0.00	no	RMSS follows profile
number_of_pulses	don't care	0	no	RMSS fills round trip time
n_bursts_in_flight	1	1	no	
percent_of_BW	100	100.0	yes	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	255.000	242.000	yes	8 to 2 reduces max data rate possible
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 10: ta div_g sar_hi_B3 block

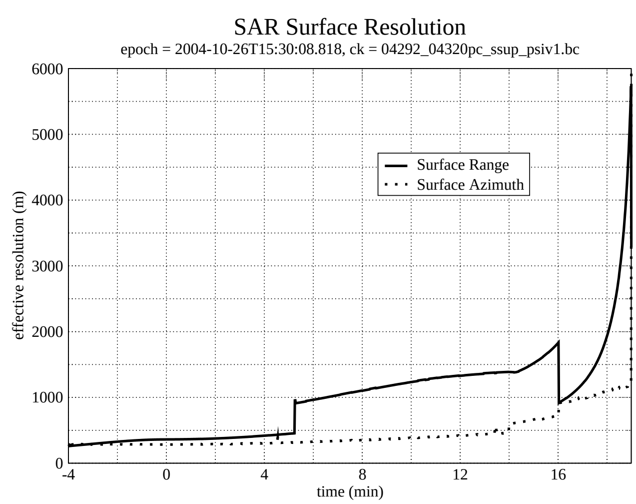

Figure 8: SAR projected range and azimuth resolution. These values are computed from the IEB parameters and are not related to the pixel size in the BIDR file. The pixel size was selected to be always smaller than the real resolution.

Name	Nominal	Actual	Mismatch	Comments
mode	altimeter	altimeter	no	
start_time (min)	19.0	19.0	no	
end_time (min)	30.0	30.0	no	
time_step (s)	don't care	3.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	7	7	no	7 - 8 to 4
csr	8	8	no	8 - auto gain
noise_bit_setting	2	2	no	
dutycycle	0.73	0.73	no	
prf (KHz)	5.00	5.00	no	
number_of_pulses	21	21	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	85.000	85.000	no	
interleave_flag	on	on	no	
interleave_duration (min)	varies	6.4	no	

Table 11: ta div_h standard_altimeter_outbound block

Azimuth resolution is a function of the synthetic aperture size which is determined by the length of the receive window in each burst (assuming the receive window is always filled with echos). Azimuth resolution deteriorates less quickly because the number of pulses and the length of the receive window are increased as altitude increases which mitigates the increasing doppler bandwidth of the beam patterns. The receive window length increases to fill the round trip time until the science data buffer is filled. At this point it is no longer possible to extend the receive window, and azimuth resolution starts to deteriorate more rapidly. For the Ta profile, the data buffer is first filled when the BAQ mode switches to 8 bits straight at 14 minutes after c/a.

10 Div H: Standard Altimeter

From 00:19:0.0 to 00:30:0.0 the instrument will operate in Altimeter mode. The division keywords are shown in Table 11

There is an issue with the pointing accuracy for altimetry. Nominally, the beam 3 boresight should be pointed at the nadir point to within a fraction of one beamwidth. However, the project predicts that pointing near Titan closest approach will not be that accurate. The problem is most acute for Ta which has the highest uncertainties in the position of Titan. Later Titan flyby's will have better pointing accuracy. It may be necessary to request a smaller deadband of 0.5 mrad for later Titan flyby's if the pointing errors prove to be small enough. For Ta, the Altimeter will be operated assuming nominal pointing. The strategy for altimetry may need to be modified later in Tour depending on pointing performance.

The PRF and number of pulses are fixed at 5 KHz and 21 pulses respectively. Unlike the SAR modes which fill the round trip time, the number of pulses in Altimeter mode is limited by the size of the science data buffer (16 K words = 32 Kbytes). The PRF value chosen is high enough to cover the doppler spread within beam 3 thus allowing for doppler beam sharpening (see Table 3 and figure 5). Assuming a locally flat surface, then range ambiguities are spaced according to,

$$\cos\theta = \frac{2a}{c\tau_{\mathrm{pri}} + 2a}, \tag{3}$$

where θ is angular separation to the first range ambiguity, a is the altitude above the surface, c is the speed of light, and $\tau_{\mathrm{pri}} = 1/\mathrm{PRF}$ is the pulse repetition interval. Using the values specified above, the first range ambiguity is about

Code	AT1	AT2	AT3	Total	at1	at2	at3
290	5	4	0	9	00101	00100	00
10	0	4	0	4	00000	00100	00
90	1	4	0	5	00001	00100	00
110	2	4	0	6	00010	00100	00
210	4	4	0	8	00100	00100	00
410	8	4	0	12	01000	00100	00
810	16	4	0	20	10000	00100	00
200	4	0	0	4	00100	00000	00
204	4	1	0	5	00100	00001	00
208	4	2	0	6	00100	00010	00
210	4	4	0	8	00100	00100	00
220	4	8	0	12	00100	01000	00
240	4	16	0	20	00100	10000	00
210	4	4	0	8	00100	00100	00
211	4	4	4	12	00100	00100	01
212	4	4	8	16	00100	00100	10

Table 12: Attenuator sequence for testing in Div I: dB values and binary settings are shown. The test is designed to activate each of the sub-attenuators one by one to see their actual impact on the signal

24 beamwidths away from the nadir point and should not be an issue.

Given the pulse timing parameters, the burst rate is then determined by the division data rate. For Altimetry, the division data rate is limited by the available data volume. For the Ta flyby, the SAR modes are favored by pushing the instrument to the limits imposed by the geometry. The scatterometry divisions are targetted for a data rate of about 30 Kbytes/s while the Radiometry divisions need 1 Kbytes/s. This leaves enough data volume for a relatively high rate of about 85 Kbytes/s for Altimetry. Future passes may change this strategy depending on the relative performance of the different modes.

RMSS sets the transmit-receive window offset (TRO) to -6 for normal Altimeter operations. The negative TRO value means that the echo window is 6 PRI's shorter than the number of pulses transmitted. This setting increases the valid time of each radar instruction because the range-gate can vary by 6 PRI's before the echo window will see an empty PRI interval. Unlike the scatterometer mode, the negative TRO setting eliminates any noise only segments in the burst which makes the data collection more efficient. Although the Altimeter mode does not need so much noise only data (for noise subtraction and radiometric calibration) it is still desirable to occasionally see where exactly the pulse train lies in the range-gate. Therefore the interleave option will be used to insert some positive TRO bursts that will show the beginning or the end of the pulse train. The interleave keywords for this division are set to generate 2 or 3 special bursts spaced evenly in time. During the special interleaved bursts, RMSS programs 9 transmit pulses and a TRO of +6 giving an echo window 15 PRI's long. The division keyword for number of pulses is not used for these interleaved bursts.

11 Div's I-O: Scatterometer Operations

Division I is a short interval (0.6 min) included to provide space for a set of attenuator tests. RMSS will generate scatterometer mode instruction according to the parameters in table 13, however, these instructions will then be overlaid with manually generated instructions for the attenuator test. Table 12 shows the attenuator combinations that will be used to collect data with. Comparing these data will be used to evaluate the attenuator settings subject to assumptions about how the backscatter signal is changing.

Division J supplies standard scatterometer parameters for the outbound scatterometry scan.

Division K covers a 6 minute test of the compressed scatteromer mode. The compressed scatterometer mode provides on-board incoherent summation of the echos in a burst. The echos are summed by absolute value which can be scaled to power. In this mode, the data rate is reduced to about 5 Kbytes/s which covers the 2 PRI's worth of data that is downlinked in each burst. The number of pulses transmitted depends on the energy available in the energy

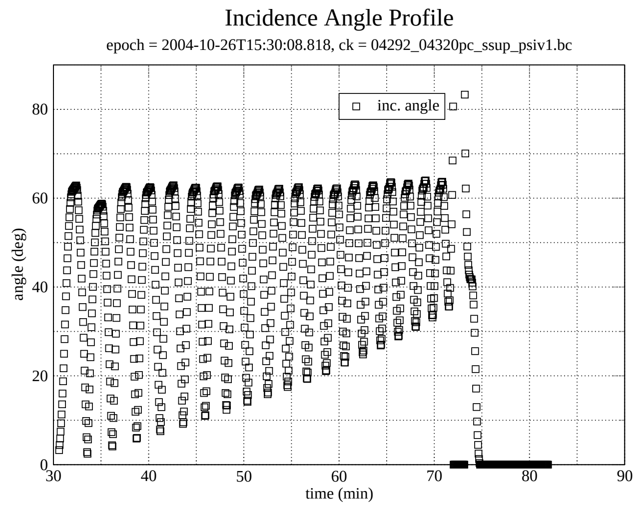

Figure 9: Incidence angle variation during outbound scatterometry scan

storage system (ESS).

During the C43 test of Ta, the last minute of this time was used to push the pulse limit. It is not necessary to repeate this test during Ta, so the whole six minutes is run with 90 pulses transmitted. Figure 9 shows the incidence angle variation during the outbound scatterometer scan and during the compressed mode test (divisions J and K).

12 Div L: Outbound Radiometry Scan

Table 16 shows the parameters for the final outbound radiometry scan. Figures 10 - 12 show the scan and the associated incidence angle variation. The Ta radiometry scan was constructed with less overlap than the designs used on subsequent Titan flyby's to ensure that the whole disk could be covered. This first radiometry map of Titan will be useful for planning subsequent data takes.

13 Revision History

1. Aug 20, 2004: Initial release
2. Sep 21, 2004: Updated merged ckernel, added attenuator test detail, added acronym list and revision history, other minor editing changes
3. Nov 05, 2004: Added section and plot on SAR resolution performance, fixed some minor errors.

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	30.0	no	
end_time (min)	varies	30.6	no	
time_step (s)	don't care	5.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	8	0	yes	0 - Normal operations without BAQ to allow for manual attenuator steps
noise_bit_setting	4	4	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.60	no	
prf (KHz)	1.20	1.20	no	
number_of_pulses	8	8	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	39.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 13: ta div_i standard_scatterometer_outbound block

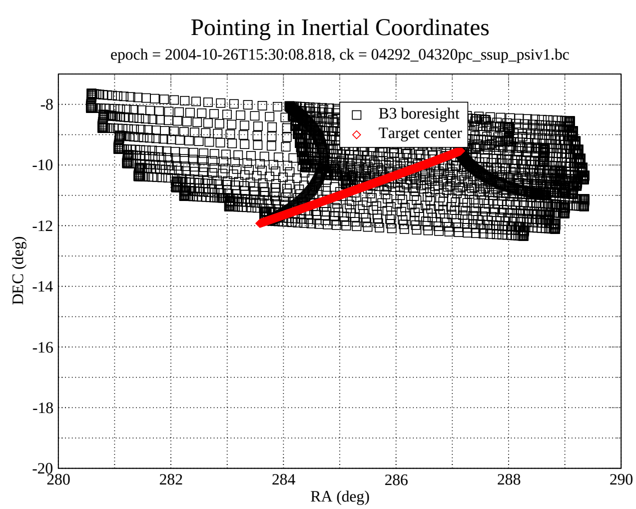

Figure 10: Outbound radiometer scan in inertial coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer	scatterometer	no	
start_time (min)	varies	30.6	no	
end_time (min)	varies	76.0	no	
time_step (s)	don't care	5.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	5	5	no	5 - 8 bits straight
csr	8	8	no	8 - auto gain
noise_bit_setting	4	4	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.60	no	
prf (KHz)	1.20	1.20	no	
number_of_pulses	8	8	no	
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	30.000	34.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 14: ta div_j standard_scatterometer_outbound block

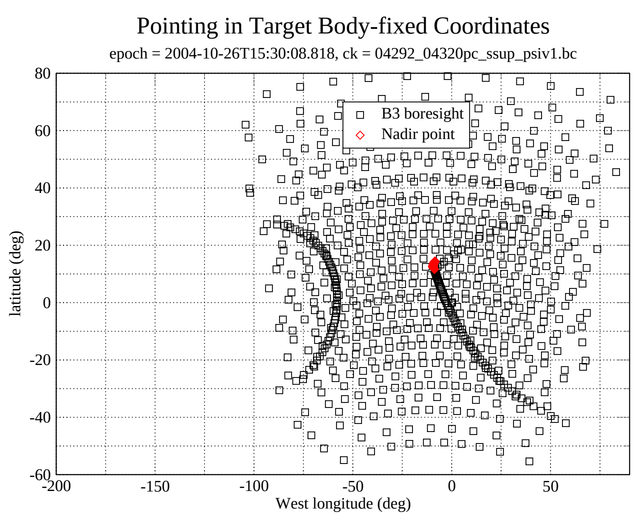

Figure 11: Outbound radiometer scan in target body-fixed coordinates

Name	Nominal	Actual	Mismatch	Comments
mode	scatterometer_compressed	scatterometer_compressed	no	
start_time (min)	varies	76.0	no	
end_time (min)	varies	82.0	no	
time_step (s)	don't care	5.0	no	Set by valid time calculation
bem	00100	00100	no	
baq	3	3	no	5 - 8 bits straight
csr	8	8	no	8 - auto gain
noise_bit_setting	4	4	no	Scat signal set higher than ALT/SAR
dutycycle	0.60	0.60	no	
prf (KHz)	1.20	1.20	no	
number_of_pulses	90	90	no	Set to the largest number that the ESS can supply - Only 2 PRI's worth of data are downlinked.
n_bursts_in_flight	1	1	no	
percent_of_BW	100.0	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	6.000	39.000	yes	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 15: ta div_k scatterometer_compressed block

Name	Nominal	Actual	Mismatch	Comments
mode	radiometer	radiometer	no	
start_time (min)	120.0	82.0	yes	
end_time (min)	300.0	330.0	yes	
time_step (s)	2700.0	5400.0	yes	Used by radiometer only modes
bem	00100	00100	no	
baq	don't care	5	no	
csr	6	6	no	
noise_bit_setting	don't care	4	no	
dutycycle	don't care	0.38	no	
prf (KHz)	don't care	1.00	no	
number_of_pulses	don't care	8	no	
n_bursts_in_flight	don't care	1	no	
percent_of_BW	don't care	100.0	no	
auto_rad	on	on	no	
rip (ms)	34.0	34.0	no	
max_data_rate	1.000	1.000	no	
interleave_flag	off	off	no	
interleave_duration (min)	don't care	10.0	no	

Table 16: ta div_l standard_radiometer_outbound block

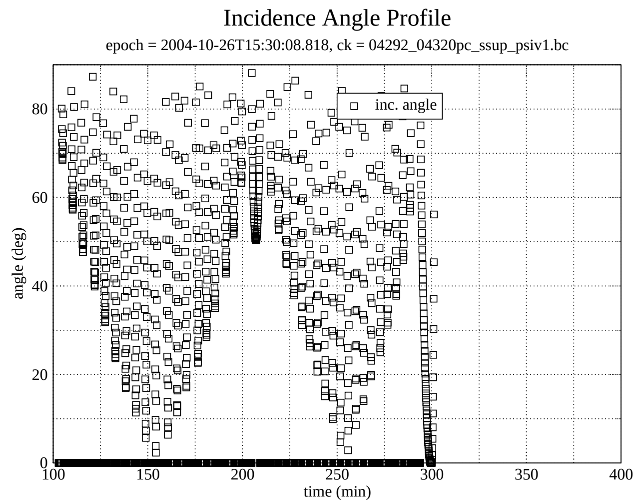

Figure 12: Incidence angle variation during outbound radiometry scan

14 Acronym List

AL	Acronym List
ALT	Altimeter - one of the radar operating modes
BAQ	Block Adaptive Quantizer
CIMS	Cassini Information Management System - a database of observations
Ckernel	NAIF kernel file containing attitude data
DLAP	Desired Look Angle Profile - spacecraft pointing profile designed for optimal SAR performance
ESS	Energy Storage System - capacitor bank used by RADAR to store transmit energy
IEB	Instrument Execution Block - instructions for the instrument
ISS	Imaging Science Subsystem
IVD	Inertial Vector Description - attitude vector data
IVP	Inertial Vector Propagator - spacecraft software, part of attitude control system
INMS	Inertial Neutral Mass Spectrometer - one of the instruments
NAIF	Navigation and Ancillary Information Facility
ORS	Optical Remote Sensing instruments
PDT	Pointing Design Tool
PRI	Pulse Repetition Interval
PRF	Pulse Repetition Frequency
RMSS	Radar Mapping Sequencing Software - produces radar IEB's
SAR	Synthetic Aperture Radar - radar imaging mode
SNR	Signal to Noise Ratio
SOP	Science Operations Plan - detailed sequence design
SOPUD	Science Operations Plan Update - phase of sequencing when SOP is updated prior to actual sequencing
SSG	SubSequence Generation - spacecraft/instrument commands are produced
SPICE	Spacecraft, Instrument, C-kernel handling software - supplied by NAIF to use NAIF kernel files.
TRO	Transmit Receive Offset - round trip delay time in units of PRI